A Microscopic Investigation of Concrete and Determination of Proportions of Materials in Made Concrete.

From a Thesis Presented for the Degree of Bachelor of Civil Engineering

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PURPOSE

1. So great has been the number of requests that have come to the Department of Civil Engineering of the Ohio State University for testing samples of concrete from structures that have failed that it was thought desirable to try to find a practical method by which the proportion of materials in the concrete could be determined. The writers of this paper have tried to find what ratio, if any, exists between the areas of the various materials exposed in a plane section of the concrete and the volume of the materials which were put into the mixture. A second purpose, no less important than the first, was the finding of a method and devising apparatus with which one could easily and quickly get convincing results.

2. The importance of knowing whether or not one has a good concrete, measuring up to specifications, is realized when one thinks of the many lives and large amount of valuable property that are dependent for the continuation of their existence upon the stability of various concrete structures. But not only should a method of determining the proportions of materials in made concrete prove valuable in "checking up" on unscrupulous contractors and in finding causes and placing blames for failures, but it also should be useful in the design of stronger and better concrete.

HISTORY

3. The only investigation of which we have record, that has been made in this direction, is that by Nathan C. Johnson, Consulting Engineer, New York City. Early in 1915 Mr. Johnson, after conducting investigations over a period of years, published a series of articles in the Engineering record, in which he advocated a greater use of the microscope in the study of concrete. Some of the possibilities of microscopic examination of concrete are: quantitative analysis of concretes; detection of impurities, such as vegetable, adhesive clay and other films on sand and stone; and the detection of impurities and adulterations in the cement.

4. The use of the microscope in which we are particularly interested is for the quantitative analysis of concretes. Mr. Johnson, after calling attention to the need for a check on the quantities used in construction and to the need for a means of making quantitative analyses of concrete of any age, outlined a method of making such analyses. He would cut a plane section, at random, from the sample or specimen to be analyzed, and on the ground that it was a random section, he assumed that it was representative of the entire mass. The truth of this assumption seemed to be borne out by the fact that there was but slight variation in various sections from a concrete with which careful methods in mixing and placing had been used.

5. Mr. Johnson then made the assumption that the ratios of the areas of the coarse aggregate, fine aggregate, cement and voids were equivalent to the ratios of their volumes. It would seem that if the first assumption were true—that the sections obtained were typical of the entire mass—the second must also be true. Granting the truth of the second assumption, the ratios of the volumes of the materials may be computed from the ratios of the areas found in a plane section. The method used by Mr. Johnson in finding the areas of the aggregates was similar to that used by the writers, and will be described below. Mr. Johnson's method of finding the ratios of the volumes was rather cumbersome, and, in fact, some of the steps are rather questionable.

6. Mr. Johnson later delivered a lecture before the Engineers' Club of Philadelphia, in which he showed the possibilities of the use of the microscope in the study and improvement of mixing methods. This lecture may be found in the Journal of the Engineers' Club of Philadelphia, 1919, or a reprint of part of the lecture may be found in Engineering News-Record, volume 82, page 1266 (June, 1919).

EQUIPMENT

7. The equipment used in these investigations consisted of tools for the analysis of the materials and for mixing and making the sample specimens, machines for cutting and polishing the specimens, and apparatus for examining the sections and measuring the areas of the different materials exposed.

8. For the mechanical analysis of the materials, there were required sieve nests with standard mesh screens, platform balances, boxes, pails, tins, graduates and other vessels with easily measured dimensions. The tools used in mixing the concrete and making the samples were trowels, mixing pans, balances or scales, and molds. Several different types of molds were used, but those preferred were the gang type in which could be made six six-inch cubes.

9. For cutting, or to use a more descriptive term, slicing the specimens, there was used an especially designed and built power saw. The cutting agent was a granular abrasive, carborundum (No. 100), one of the hardest substances known. It was carried by a stream of water onto the specimen where it was rubbed back and forth by a soft-steel, toothless saw blade. The building of the saw was done with the aid of the regular machine shop tools, such as power drill, shaper and lathe. The polishing apparatus consisted of a 14-inch rigid steel disc mounted on a vertical axis, upon which, when rotating at high speed, was held the block to be polished. Fine carborundum was fed onto the wheel to provide

abrasion. For the first smoothing down of the rougher sections a piece of a large emery wheel was available.

10. Permanent record of the section was made by photographing them with a 5″ by 7″ camera having an anastigmat lens. Standard orthonon plates were used. For making photographs of the finer structure — photomicrographs—there was available a special camera, manufactured and sold by Bausch and Lomb, used in connection with a metallurgical microscope of standard design. For measuring the areas of the materials in the gross sections polar planimeters were used. A cross-ruled screen in the eye-piece of the microscope aided in getting the areas in the microscopic sections.

METHOD USED

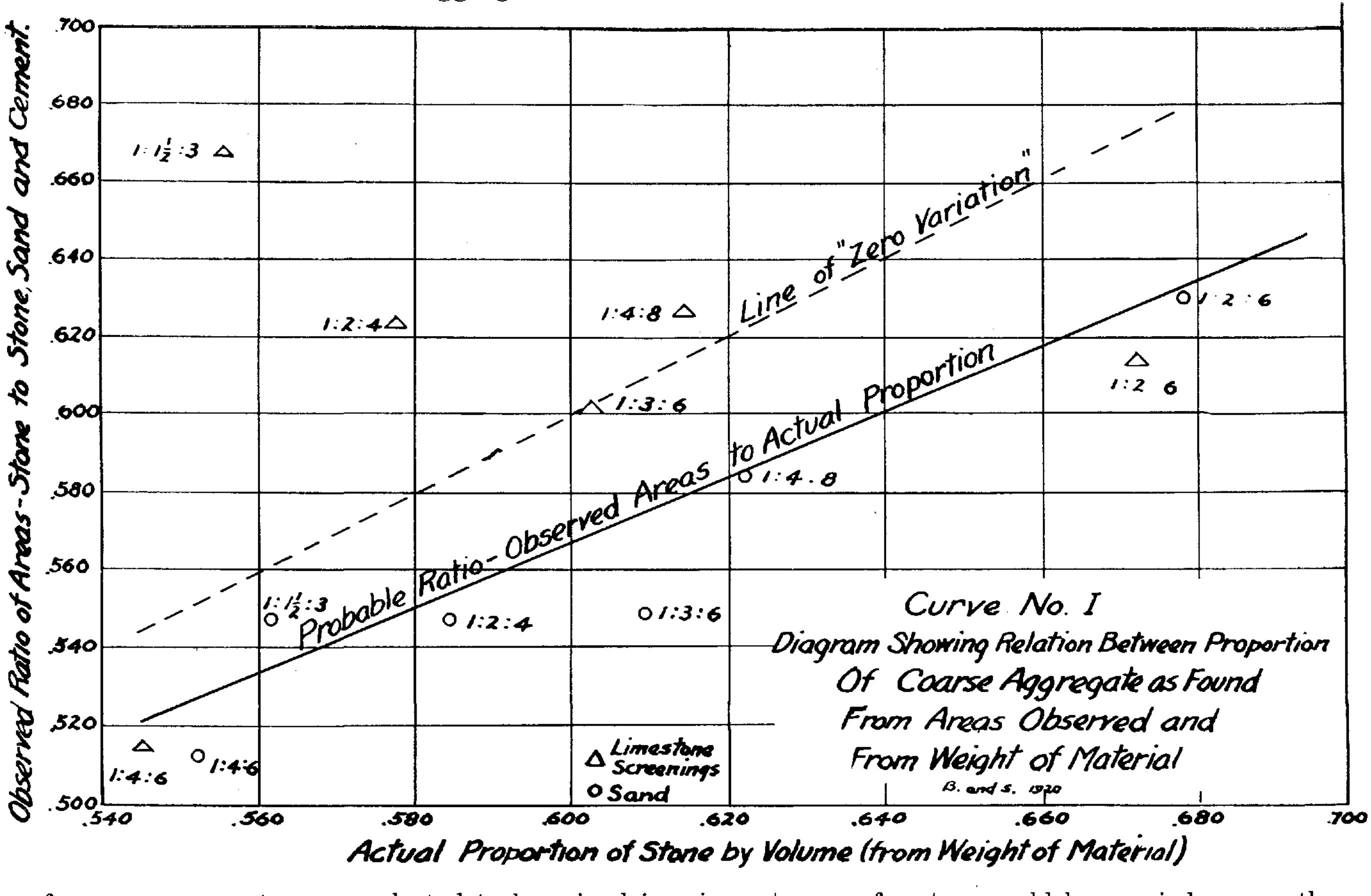
11. The first action taken was the determination of the kinds of materials and the mixes to be used. Three kinds of fine aggregate and two of coarse aggregate were selected to be mixed in the six different proportions. Under these conditions the greatest possible number of combinations was thirty-six.

12. Representative samples of each of the materials were secured by thorough mixing and careful separation. These were run through sieves and the percentage of the total amount caught on each sieve was determined. Knowing the sizes of the sieve openings we were able to determine what part of the material was of certain sizes. Curves were plotted with the results of these sieve analyses. The weights and specific gravities of the materials were determined by comparison with equal volumes of water. Tests were made on the cement to determine the amount of shrinkage upon mixing with water.

13. Enough material was separated out for each batch to make a cube six inches on a side. In mixing the materials all proportioning was done by weight. Accurate account was kept of all the quantities used, including the amount of water. Care was taken to use just enough water to hydrate the cement and make workable mixes. Immediately after mixing, the concrete was placed in the molds where it remained for several hours, until final set took place. The specimens were then removed, marked with a serial number, and stored in a dry place.

14. One of the main difficulties met with was finding a method of cutting through the blocks. Already at hand was a device for sawing concrete, consisting of a thin sheet iron disc mounted so as to revolve on a vertical shaft. Power was furnished by an electric motor. If a block of concrete was held against this toothless saw, a granular abrasive such as carborundum fed on in a stream of water would be carried across the surface of the concrete by the saw and would perform the cutting. This saw was not adapted to the cutting of a great number of blocks, because it was necessary for someone to be constantly in attendance to keep the block adjusted and to feed the abrasive.

15. On the bed of this old saw a new one similar to a power hack-saw was built, after considerable study and labor. The new saw was driven by the motor already in place. The operation of this piece of apparatus was quite simple. A block to be cut was clamped under the blade, adjustment made of the stream of water which carried the abrasive, and the power switch opened. The water-borne abrasive was worked back and forth across the top of the concrete block under the



toothless, soft-steel saw-blade and performed the cutting action. A device was arranged which would, when the cut through the block was made, shut off the power, thus preventing waste of power and injury to the apparatus. Since most of the operations were automatic, the saw required little attention, except the changing of the concrete blocks, replenishing the supply of abrasive and water, and changing the saw blades. As it required from four to twelve hours, depending upon the kind of material in the specimen, to saw through a block of concrete, these automatic devices effected a great saving of time.

16. The chief source of trouble with the new saw was the abrasive feed apparatus. It was so arranged that with each stroke of the saw a small valve in the bottom of the miniature bin, a few inches above the saw, was opened and a certain amount of the granular carborundum flowed out, down a chute onto the saw blade. On the same spot water was constantly dripping, giving to the abrasive greater mobility. The water, carborundum dust and small stones dislodged from the concrete were caught below in a pan. The material collected in the pan was saved, and when a large enough amount had accumulated, the fine dirt was washed from it, the residue dried and sifted. The carborundum recovered could be used again. It was, however, impossible in any reasonable length of time to free the abrasive from all dirt, and after it had been used several times, it contained enough dirt to clog the feed valve. To make the problem worse, the proper regulation of the dripping water was difficult to attain. If the water ran too slow the abrasive was not carried down into the saw kerf, or if the flow was too fast the abrasive was carried away before its usefulness was developed.

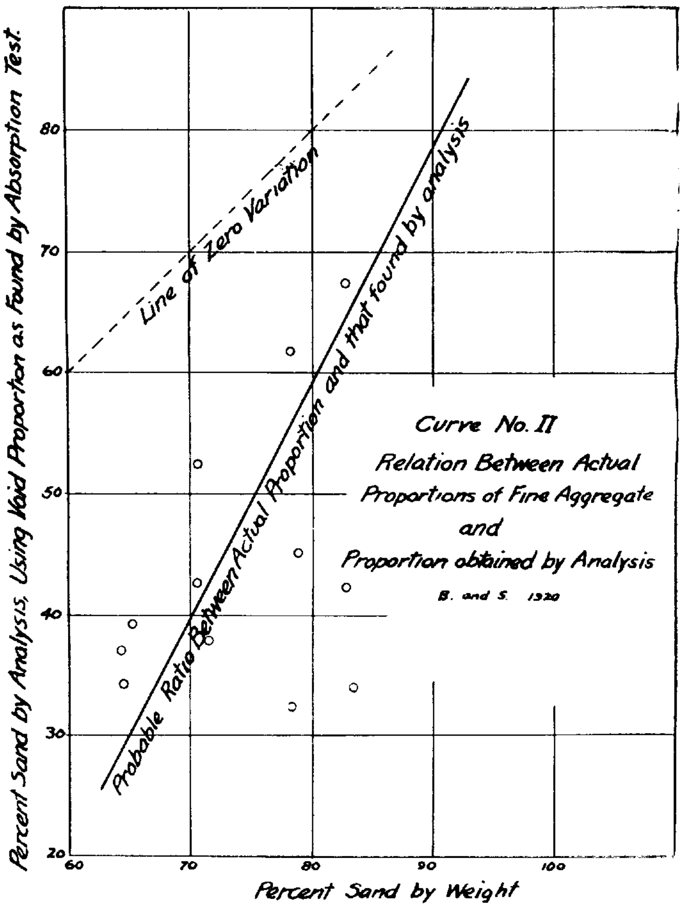
17. Some of the cross sections could be used just as they came from the saw, but the majority of them required some polishing. The rougher sections were given a preliminary smoothing by rubbing for a few minutes on a piece of a large emery wheel. The final smoothing was done on the steel polishing wheel mentioned above.

18. For microscopic work a much smoother surface was necessary. Small pieces of mortar, containing no large aggregate, were broken from the large specimens, and an attempt was made to secure a suitable surface by polishing on the steel polishing wheel, and then finishing by hand with a small carborundum stone. In spite of the extreme care taken, the surface, when placed beneath the microscope, showed many places where small particles had been dislodged from the matrix or mortar. This condition was remedied somewhat by boiling the small specimens in a solution of Canadian balsam and chloroform. The samples could then be ground on the polishing wheel with dislodgment of very few of the particles.

19. In order to have a permanent record of the surface examined, photographs were made of the gross sections. The work was done with the camera mentioned above, under artificial light—that being of more even intensity than daylight. Some of the surface was dampened before photographing so as to produce a little more contrast. The numbers of the samples were placed on the surface, also, before photographing so that there would be no possibility of getting the numbers of the negative mixed. These photographs were made natural size so that one looking at them might get a true idea of the appearance of the sections.

20. The areas of the coarse aggregate were first measured with a polar planimeter from the photographs. It was found easier, however, to work from the actual surfaces because it was sometimes difficult to tell from the photographs where aggregate left off and matrix commenced, especially where the stone and mortar were of nearly the same color.

21. The best of the photomicrographs were quite indistinct and so it was practically impossible to measure the areas of the fine aggregate



from these. Besides, if the method were possible, the labor and expense of making negatives and prints of a sufficient number of sections to secure a workable average would prohibit its application. Mr. Johnson's method was to erect a small platform on a level with the ground glass of the microphotographic apparatus and with a planimeter on this platform, measure the areas of the fine aggregate directly from the image on the ground glass. This method was thought out of the question, on account of the indistinct images secured on the ground glass. The plan at last adopted was to place in the eye-piece of the microscope a thin glass screen upon which were lines cross ruled. The spacing of these lines was such that the diameter of an object on the stage below whose image just lay between two of the lines, was exactly an unit length, say one one-hundredth of an inch. With this device it was possible to estimate the areas of the fine aggregate and the voids of the specimen. The difference between the areas of the fine aggregate and the voids, and the area of the whole field under observation was the area of the cement in the surface. Some difficulty was experienced in distinguishing the coarse particles in the cement from the fine particles in the sand. This was largely overcome by having a sample of hydrated neat cement close at hand for frequent reference. Several fields were observed in the same sample of mortar and a mean taken of the results.

22. The results obtained, when the proportion of materials was computed from the relative areas, did not compare favorably with the actual values—the values as computed from the weights of the materials used in making the specimens. Investigation showed that a certain class of aggregate was being missed. The smallest area that could be easily noted with the naked eye was about one-tenth of an inch in diameter. The field of the lowest power (50 diameters) of the microscope was about seven hundredths of an inch in diameter. The area of that part of the aggregate lying between these two sizes could not be measured conveniently. The solution would seem to be to secure an instrument capable of using lower powers, say about twenty diameters, and having a larger field, at least one-fourth inch in diameter.

23. Considering the ratios of the areas of the materials equal to the ratios of their respective volumes, comparison was made between the volumes computed from the areas and the volumes computed from the weights of the materials used in the making. These comparisons were made in two different ways. Tables were prepared which showed the percentage variation of the values found by analysis from the values computed from the weights. Curves plotted from these percentages showed graphically the general law of variation. It was found, also, that after handling many of these specimens one could recognize by sight the various proportioned mixes.

DISCUSSION

24. An examination of the curve of coarse aggregate ratios disclosed the fact that, with small variation for the different mixes, the true proportion of the coarse aggregate in the specimens might be obtained by multiplying the observed proportions by a constant which was slightly above unity (1.06). A similar constant for the fine aggregate cannot be so easily found, on account of the greater variations for the different mixes, which in turn is probably due to the inability to measure all the fine aggregate areas, as explained in paragraph 22. A constant for the richer mixes would be about 2.2, while for the leaner ones it would approach unity, reaching that point when there was no cement in the field observed. It was thought that the best way of finding the actual values of the proportion of fine aggregate from a value as computed from areas in a section is by use of a curve such as may be found in Diagram II. The proportion of cement in the mortar is found by subtracting the proportion of fine aggregate from 1.00. It was thought that one of the quickest and easiest ways of making an estimate of the proportions of materials in a concrete was comparison of the general appearance of a section of the concrete of unknown proportions with sections or photographs of sections of the same or similar materials of known proportions.

25. It will be noted that the points from which the two curves, referred to in the preceding paragraph, were plotted are widely scattered and, consequently, the locations of the curves may be in error. Their present locations were found by careful averaging of the points. It must be remembered that these specimens are laboratory mixed and that in the field quite different conditions govern the mixing and placing of concrete. For this reason somewhat greater variation in results would be expected from tests run on field mixed concrete.

26. With some further investigation, to determine with greater accuracy the ratio of proportions observed to actual proportions in the concrete, the above methods of analysis might be used in the commercial testing laboratory. It is suggested that examination be made of a greater number of specimens, mixed and placed under various conditions, and that several sections in each sample be analyzed. It is hoped that in this way the average values of all quantities may be found.

27. Some changes in the operations in preparing and analyzing the specimens might be made. It is suggested that an attempt be made to find a better method of reclaiming abrasive after it passes through the saw. Perhaps some method of winnowing the dust from the carborundum could be devised. Also a positive acting water control for the abrasive feed apparatus would expedite the sawing. It is further suggested that for the cross-ruled glass screen in the eye-piece of the microscope (as described in paragraph 21), a reticule with spider cross-hairs be substituted.

28. It is hoped that these investigations of the possibilities of the microscope in the quantitative analysis of concrete will be taken up and continued by others, for it is only after much observation and discussion that the truth and usefulness of an idea is fully realized.

HE IS THE RICHEST MAN—

Who values a good name above gold.

In whose possession others feel rich.

Who can enjoy a landscape without owning the land.

Who has a mind liberally stored, cultivated and contented.

Who can face poverty and misfortune with cheerfulness and courage.

For whom plain living, rich thinking and grand effort constitute real riches.

Who has a hearty appreciation of the beautiful in nature and in human beings.

Who carries his greatest wealth in his rich personality and fine character.

Who absorbs the best in the world in which he lives and gives the best of himself to others.

The peculiarity of all art is that it cannot be communicated in writing alone, craft is a term which is synonymous with art; a craft requires manual dexterity which cannot be taught in books.